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SEMICONDUCTING TRANSITION METAL SILICIDES: NEW  
MATERIALS FOR OPTOELECTRONICS ON SILICON(U) COLORADO  
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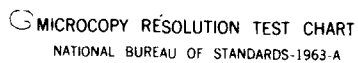
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Semiconducting transition metal silicide thin films of $\text{FeSi}_{1.75}$ , $\text{MnSi}_{1.75}$ , $\text{CrSi}_2$ , $\text{ReSi}_2$ , and $\text{IrSi}_{1.75}$ , were prepared. The electronic band structures were probed with measurements of the optical properties as a function of photon energy, together with measurements of the electrical resistivity as a function of temperature. The iron and manganese silicides possess direct forbidden energy gaps of 0.89 and 0.68 eV, respectively. The chromium and rhenium silicides exhibited apparently indirect gaps of slightly less than 0.35 and 0.12 eV, respectively. The bandgap of $\text{IrSi}_{1.75}$ is close to that of silicon and could not be determined with the techniques available to us in this research. Applications for the semiconducting silicides, in optoelectronic chip interconnects and infrared detection, are noted. Reprints. JES				
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SEMICONDUCTING TRANSITION METAL SILICIDES: NEW MATERIALS  
FOR OPTOELECTRONICS ON SILICON

Final Report

Professor John E. Mahan

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### The Problem Studied

The purpose of this work was to examine the suitability of some semiconducting transition metal silicides as active optoelectronic device materials. These materials are  $\text{IrSi}_{1.75}$ ,  $\text{FeSi}_2$ ,  $\text{MnSi}_{1.7}$ ,  $\text{CrSi}_2$ ,  $\text{LaSi}_2$ , and  $\text{ReSi}_2$ . The motivation for the research was the ultimate desire to develop an optoelectronic device technology where both light sources and intrinsic semiconductor detectors may be monolithically integrated on a silicon chip.

The materials were prepared as thin films on silicon substrates. The silicide phases were formed by furnace reaction of sputter-deposited metal films with the substrates.

### Summary of Results

Since the last progress report we have completed our optical analysis of four semiconducting silicides. We will summarize our results for these materials now in order of increasing bandgap:

$\text{ReSi}_2$  possesses an indirect bandgap of slightly less than 0.12 eV. The uncertainty is due to the fact that our measurements (of the phonon emission branch of the optical absorption constant) can only give us  $E_G + E_p$ , the bandgap plus the assisting phonon energy for the indirect transition. (The phonon absorption branch of the absorption spectrum was not experimentally accessible; if it were, then  $E_G$  and  $E_p$  could have been separately determined.) With typical phonon energies of a few hundredths of an electron volt, we can say that the bandgap is  $\sim 0.1$  eV. In addition, we observe a direct transition at 0.36 eV.

$\text{CrSi}_2$  similarly possesses an indirect gap of slightly less than 0.35 eV and also exhibits an apparently direct transition at 0.67 eV. The uncertainty in bandgap value is due to the same reasons as for  $\text{ReSi}_2$ .

$\text{MnSi}_{1.7}$  displays a direct bandgap of 0.68 eV and there is evidence of



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another direct transition at 0.82 eV.

Beta-FeSi<sub>2</sub> exhibits a direct gap of 0.89 eV. In these polycrystalline films we see extrinsic transitions at 0.38 and 0.14 eV, as well.

We find LaSi<sub>2</sub> to be a metal, rather than a semiconducting material as was indicated by our literature survey included in the proposal for this research. Metallic behavior was observed for both the low temperature tetragonal and high temperature orthorhombic phases. Their room temperature resistivities were found to be 24 and 57 micro-ohm-cm, respectively.

IrSi<sub>1.75</sub> appears to possess a forbidden energy gap very near to that of silicon. This fact made it impossible for us to optically characterize the material in detail. Strong absorption by the silicon substrate obscured the optical properties of the silicide films.

We would like to note some potential technological applications of the first four materials for which results were summarized above. The two larger bandgap materials, by virtue of their direct bandgaps, may lend themselves to the creation of efficient solid state light sources. The direct gap is generally a requirement for efficient radiative recombination. Much work remains to be done, however, to achieve single crystal films and to investigate device physics. The bandgap values correspond to wavelength values (1.39 and 1.82 microns) that may be usable with silica-based optical fibers.

The two smaller bandgap materials probably will not lend themselves to the development of solid state light sources, because of their indirect gaps. However, their bandgap values correspond to wavelengths (~3.5 and 10.3 microns) of considerable interest for terrestrial infrared imaging, because they lie within atmospheric transmission windows.

Finally, we would like to emphasize that, while we believe our analysis

of our polycrystalline films is solid, our results should be viewed with some caution until they are confirmed with measurements on, and analysis of, low defect density epitaxial films. In this regard, we are pleased to note that we have just received in our lab a new silicide MBE system manufactured by Perkin-Elmer. It is our desire to use this new growth system in the final year of the project (sponsored by the NSF) to make higher quality films for optical and photoelectronic characterization. The ARO will be advised of any additional results of significance and credited for any forthcoming publications.

#### Publications

M.C. Bost and J.E. Mahan, "Semiconducting Silicides as Potential Materials for Electro-Optic VLSI Interconnects," J. Vac. Sci. Tech., B4(6), 1336 (1986).

M.C. Bost and J.E. Mahan, "An Optical Determination of the Bandgap of the Most Silicon-Rich Manganese Silicide Phase," J. Electronic Materials, Vol. 16, No. 6, 389 (1987).

M.C. Bost and J.E. Mahan, "An Investigation of the Optical Constants and Bandgap of Chromium Disilicide," J. Appl. Phys. 63 (3), 839 (1988).

M.C. Bost and J.E. Mahan, "A Clarification of the Index of Refraction of Beta-Iron Disilicide," to appear in J. Appl. Phys.

R.G. Long, M.C. Bost, and J.E. Mahan, "Optical and Electrical Properties of Semiconducting Rhenium Disilicide Thin Films," to appear in Thin Solid Films.

R.G. Long, M.C. Bost, and J.E. Mahan, "The Metallic Behavior of Lanthanum Disilicide," submitted to Applied Physics Letters.

#### Conference Presentations

M.C. Bost and J.E. Mahan, "Semiconducting Silicides: Potential Materials for Electro-optic VLSI Interconnects," Electronic Materials Conference, Amherst, MA (June 25-27, 1986).

M.C. Bost and J.E. Mahan, "Semiconducting Silicides: Potential Materials for Electro-optic VLSI Interconnects," 4th Workshop on Refractory Metals and Silicides, San Juan Bautista, CA (May 12-15, 1986).

Robert G. Long, M.C. Bost, and John E. Mahan, "ReSi<sub>2</sub>, a Narrow Bandgap Semiconductor," Workshop on Metals, Dielectrics, and Interfaces for VLSI, San

Juan Bautista, CA (May 9-12, 1988).

Robert G. Long, Melton C. Bost, and John E. Mahan, "Rhenium Disilicide: A Potential Material for Optoelectronic Integration," submitted to the 35th National Symposium of the American Vacuum Society.

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